IDENTIFICATION

Title:	**Evaluation of the foundation movements of transportation structures**
Proposing Research Agency:	University of Wisconsin-Madison Department of Civil and Environmental Engineering 750 University Avenue, 4th Floor Madison, WI 53706
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Date Submitted: Date Revised:	February 26, 2008 December 3, 2008

1. PROBLEM STATEMENT

Design of foundations for transportation structures in Wisconsin is based on the AASHTO design code which uses Load and Resistance Factor Design (LRFD) methods. This design code specifies that in addition to satisfying the requirement of global stability, the structure must also have acceptably low horizontal and vertical movements to satisfy in service requirements. Historically, deep and shallow foundations were assumed to have small vertical and horizontal deformations, provided they had a high factor of safety relative to ultimate capacity. However, foundations for transportation structures, such as bridges or retaining walls, will experience vertical as well as horizontal movements due to the applied loading and additional information is necessary so that design assumptions related to foundation movements can be refined.

For deformation analyses in relation to axial loading, main areas which require additional information include:

(i) Selection of soil stiffness for input to models. Selection of soil stiffness is complicated by the nonlinear decrease in soil stiffness with increasing strain level as well as a nonlinear dependency on stress level.

(ii) Influence of foundation type (i.e., shallow foundation, driven pile, bored pile), foundation geometry, foundation stiffness, soil stiffness, and soil layering on stresses transferred to the soil and the associated foundation movements.

For horizontal deformations of deep foundations many highway agencies use the software program LPILE, which is based on the Winker spring method using input p-y curves. While ‘standard’ curves exist for different soil types within the program, there is significant uncertainty in the input parameters for these curves which are typically based on laboratory test data. These uncertainties are greater for working levels of deformation, where calculations are strongly influenced by selection of an ‘initial’ stiffness (e.g., Robertson et al. 1989, Ashford & Juirnarongrit 2003). This initial stiffness can not be measured accurately using conventional laboratory tests (e.g., Atkinson 2000). Field measurements of stiffness are more reliable for working loads, although, the conversion of in situ test data to p-y curves typically uses local correlations that have not been calibrated for soils typical of Wisconsin. The assumptions and performance of these empirical correlations need to be compared to larger databases of load test results with adjacent in situ test data, analyzed so that the influence of design method formulation can be quantified, and validated with field measurements of foundation performance in Wisconsin soil conditions.

2. RESEARCH OBJECTIVES

The overall research objective of this study is to produce a document summarizing simplified design procedures for evaluation of foundation movements for transportation structures within the LRFD framework. Recommendations for the measurement and selection of input parameters for those design procedures will also be provided. The tasks associated with these objectives can be summarized in four main areas:

(i) Develop a database of load tests with adjacent in situ test data from published sources, the Wisconsin department of transportation (DOT), as well as other state DOTs.

(ii) Analyze the performance of existing methods for analysis of foundation movements and summarize their strengths and weaknesses.

(iii) Consider differences in design method formulations, and discuss the effects of extrapolation of these methods from typical database conditions to foundation geometries, loading conditions, and soil types typically encountered for transportation projects in Wisconsin.

(iv) Collect and interpret field measurements of foundation loads and movements from transportation projects in Wisconsin for validation / update of design method formulation and selection of input parameters.

3. BACKGROUND AND SIGNIFICANCE OF WORK

3.1. Axial Loading

Settlements (s) due to axial loading of deep and shallow foundations can be modeled reliably using elastic theory, provided that an appropriate 'operational' stiffness (E) and influence factors (I) can be selected. For deep and shallow foundations, design equations can be presented as:

Deep Foundations: $$s = \frac{P \cdot I_\rho}{D \cdot E_{sL}}$$

where P is the applied load at the pile head, D is the foundation diameter, E is the 'operational' elastic modulus of the soil at the pile tip, and I_ρ is an 'influence factor.' Analysis of deep foundation axial movements using linear and non-linear stiffness methods are shown in Figure 1. It can be seen in Figure 1a that the use of a constant modulus can provide a reasonable average prediction (provided that the appropriate modulus and influence factors are selected), while in Figure 1b the use of a nonlinear soil modulus matches the foundation settlement behavior from working loads to failure in a more realistic manner. Winkler models using t-z curves require similar theoretical assumptions (e.g. Zhu & Chang 2002), although t-z curves are typically less reliable without site specific calibration due to their basis on local empirical correlations.

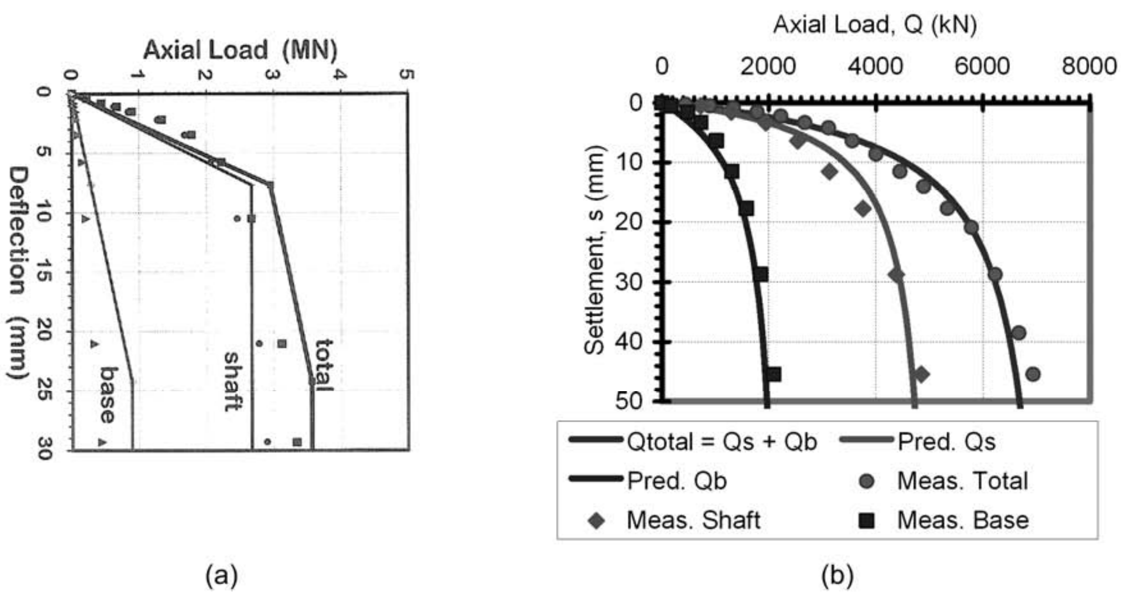


Figure 1. Modeling drilled shaft behavior using elastic theory with (a) linear dilatometer stiffness (Mayne, Martin, and Schneider 1999); and (b) non-linear stiffness (Mayne & Schneider 2001).

Shallow Foundations: $$s = \frac{q \cdot B \cdot I}{E}$$

where q is the applied stress, B is the foundation width, E is the 'operational' elastic modulus of the soil, and I is an 'influence factor.' Influence factors are affected by foundation stiffness, foundation geometry, soil stiffness profile, as well as soil layering, and have been presented in for typical design situations (e.g., Banerjee 1978, Randolph & Wroth 1979, Poulos 1987, Poulos 1989, Mayne & Poulos 1999).

While these relatively simple methods exist, there are still significant levels of uncertainty in application of the equations in practice. In a recent international shallow foundation settlement prediction symposium (conduction in collaboration with the PI) a majority of participants significantly *under* predicted footing settlements for 4 square foundations on a medium dense sand loaded to 20 tons. Of the 26 written submissions from 7 countries (with over half from the US) the average level of under prediction of settlements was by more than a factor of 2, with some predictions being un-conservative by a factor of *over 10*. The footing widths were 0.67m, 1m (two footings), and 1.5m, and comparison of the distribution of predictions to the measured settlement for a load of 280kN are summarized in Figure 2a. While the mean prediction was reasonable for a footing width of 1.5m (q=125 kPa), the Coefficient of Variation (CoV ≈ σ_{ln}) was approximately 75 to 100% for each footing size and the level of under prediction of settlement increases with stress level (Figure 2b).

This large CoV (uncertainty) comes from (i) the large number of different predictive methods used (i.e., 15); as well as (ii) the significant uncertainty in selection of an 'operational' level of stiffness. Within the footing settlement prediction competition, the Schmertmann (1970) method was the most commonly used procedure, although the primary input parameter for that method (i.e., E/q_c) varied between predictors from 2 to 24. Use of a constant linear modulus, or modulus which does not degrade in an appropriate manner with strain, caused the trend in the ratio of measured to predicted settlements (s_m/s_p) illustrated in Figure 2b.

Increases in strain level result in a non-linear degradation of soil stiffness. For an equivalent surface load, different 'operational' stiffness values are required for foundations of different widths, as shown in Figure 3b. Soil stiffness non-linearity, the resolution of laboratory measurements of stiffness, as well as disturbance induced during soil sampling all lead to uncertainty in selection of an appropriate stiffness value and influence the high levels of uncertainty in calculation of foundation movements illustrated in Figure 2.

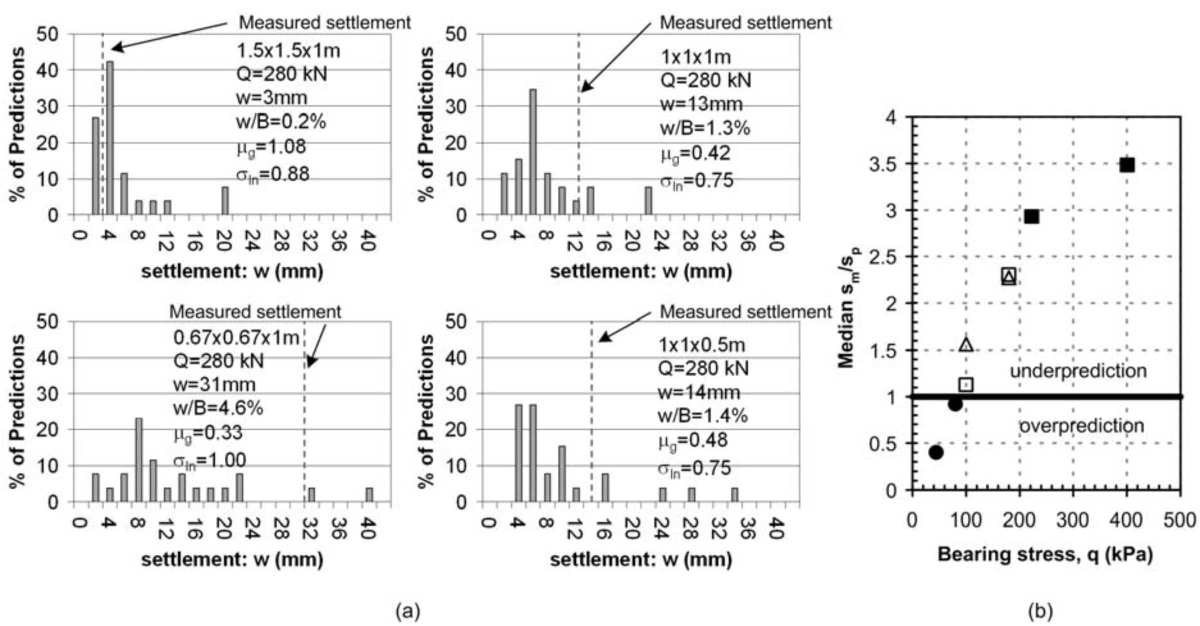


Figure 2. Results of shallow foundation in sand prediction symposium (a) distribution of predictions and field measurements at a load of 280 kN (b) level of over / under prediction as a function of foundation bearing stress (after Lehane, Doherty, & Schneider 2008)

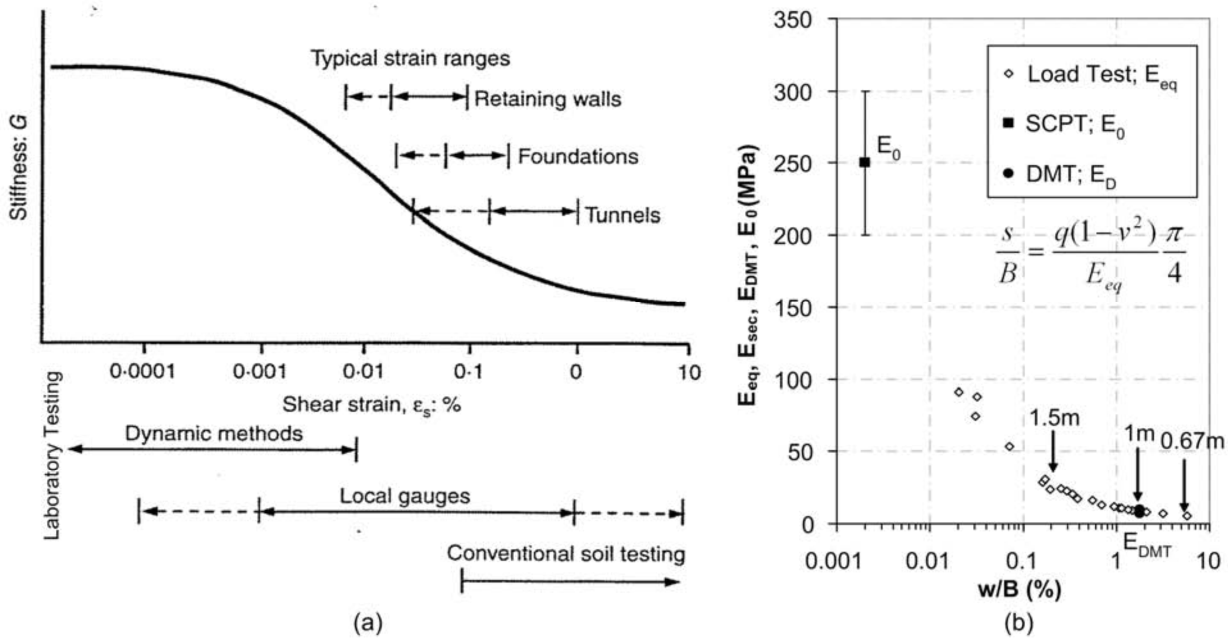


Figure 3. Nonlinear soil stiffness behavior (a) in laboratory testing and design applications (Atkinson 2000); and (b) in situ testing and shallow foundation loading in a uniform sand (after Lehane, Doherty & Schneider 2008)

3.2. Lateral Loading

Unlike the case of axial loading of piles, accounting for nonlinear stiffness characteristics of soils is more routine for lateral pile analyses, specifically, through the use of nonlinear p-y curves in computer programs such as LPILE. Still there are significant levels of uncertainty in these design methods due to their highly empirical formulations (as discussed by Robertson et al. 1986, among others), as well as their basis on laboratory testing of soils. In situ testing using the pressuremeter and flat plate dilatometer provide a repeatable measurement of stiffness and indication of strength under horizontal loading conditions, which are similar cases to lateral loading of piles. Analysis of lateral pile p-y curves using the results of these in situ tests is therefore a logical step for routine deformation based design of transportation structures, with current design methods presented by Gambin (1969), Ménard (1975), Baguelin et al. (1978), Suyama et al. (1982), Briaud et al. (1982), and Robertson et al. (1983) for the pressuremeter, and by Robertson et al. (1989) and Gabr et al. (1994) for the flat plat dilatometer. Procedures based on in situ tests are still empirical and movements at working loads are very sensitive to selection of the soil stiffness (e.g., Robertson et al. 1989). As illustrated for the shallow foundation example in Figures 2 and 3 there is a high level of uncertainty in evaluation of 'operational' soil stiffness values by practicing engineers since, historically, deformation analyses typically have not been performed (e.g., horizontal and vertical movements have been assumed to be small when a sufficiently high safety factors is applied).

3.3. Characterization of Soil Properties for Deformation Calculations

Selection of in situ testing methods for characterization of nonlinear stiffness behavior for use in foundation deformation calculations requires two primary considerations: (i) Is the in situ test method rapid, repeatable, and cost effective for the geologic conditions associated with the design situation? and (ii) Can appropriate stiffness values for use in deformation calcuations be evaluated from the test method? For most foundation considerations, the pressuremeter is an idea tool since it can be used to assess not only stiffness characteristics at a give strain level, but also provides and indication of the soils entire stress strain curve (e.g., Palmer 1972, Prevost & Høeg 1975). Pressuremeter installation and deformation measurement methods need careful consideration, with the pre-bored pressuremeter being more applicable in stiff soils and soft to weak rocks as disturance during installation tends to adversly effects measurements in softer soils. In softer soils, the more rapid and repeatable testing procedure of the flat plate dilatometer (DMT), as well as the superior level of vertical profiling of changes in soil stiffness, make the DMT a more suited test for deformation measurements in many soils types. As the DMT provides only one level of stiffness at strain levels of approximately 1.8 percent, a supplemental measuremnt of small strain stiffness in seismic DMTs (e.g., McGillivray & Mayne 2004) is desireable for deformation calcuations. Site characterization data available at the each test site will be used for evaluation of operational stiffness values within the previously discussed nonlinear framework. When data from multiple measurements are available, such as CPT, SPT, and PMT for the Marquette Interchange, appropriate design correlations will be evaluated.

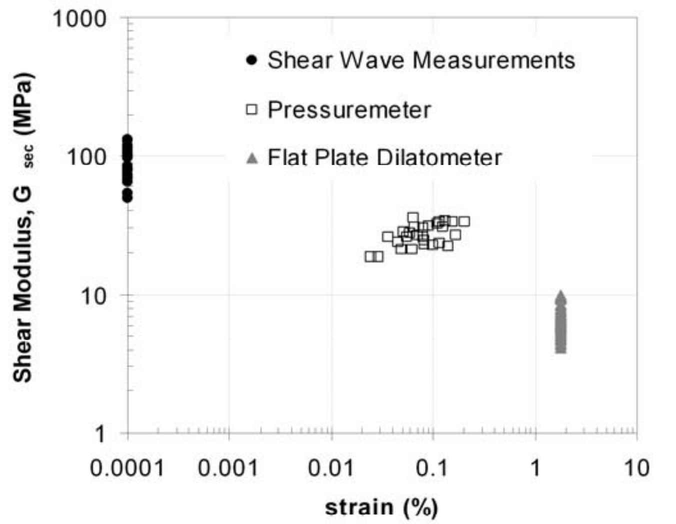


Figure 4. Influence of strain level associated with in situ testing methods on measured shear modulus at a medium dense sand site (after Schneider et al. 2008)

3.4. Significance of Research

This research effort will be an extension and improvement over previous similar studies due to:

- Combination and extension of existing databases of foundation movements, as well as analysis of the effects of extrapolation of those databases to foundation geometries, loading conditions, and soil types typically encountered for transportation projects in Wisconsin.
- Clear discussion of the influence of nonlinear stiffness characteristics of soils on foundation deformations, and best ways to assess those nonlinear characteristics using conventional site characterization methods.
- Measurement of load and deformation data for transportation structures in Wisconsin which will allow for local calibration of design procedures and input parameters developed from database studies.
- Results of database studies, finite element analyses, and field measurements will be simplified into tables and design procedures which can be efficiently and reliably used for transportation projects in Wisconsin. A discussion of advantages and disadvantages of various design methods and testing techniques will supplement these results.

4. BENEFITS

The benefits from this research project will result in improved procedures and increased efficiency, namely through simplified procedures for selection of nonlinear stiffness characteristics of soils as well as methods for incorporating these values into routine design. This will in turn result in the potential for significant cost savings, whether that is a consequence from more efficient foundation solutions or lower operational and maintenance costs. Figure 2 clearly indicates that there is a need for improved procedures to quantify horizontal and vertical movements of foundations. This need will be addressed through presentation of tabulated parameters for typical idealized conditions as well as simplified models and recommendations for the input parameters to those models.

5. IMPLEMENTATION

This research program is designed so that results of the study can be immediately and directly adopted into WisDOT practice. The findings will be presented as a procedural manual for calculation of foundation movements for transportation structures in Wisconsin. The manual will also address field testing procedures and selection of stiffness properties for input to the models. Simplified tables will be presented for typical design situations encountered by WisDOT, such as a table of typical lateral deformations in relation to pile types and soil conditions for standardized horizontal foundation loads.

6. DETAILED WORK PLAN

6.1. Literature Review

The literature review will assess two main issues:

(i) instrumentation and measurement of the movements of transportation structures; and

(ii) performance of design methods using databases of foundation load tests with adjacent in situ test data.

6.1.1. Instrumentation

The selection of instrumentation for active projects is significantly different than for load testing of isolated foundations. The instrumentation programs are intended to accurately assess loads and foundation movements over the construction process as well as for an amount of time past the end of construction. As this research project is limited to 3 years, target monitoring durations will be one to two years in length. It is anticipated that 2 to 3 sites will be instrumented in the spring of the first year of the project (two years monitoring), with the remaining sites instrumented the following year (1 year monitoring). Instrumentation is anticipated to be left in place such that longer term monitoring can be performed if desired.

The use of load cells, displacement transducers, and reference beams commonly used for load testing of foundations are generally not practical for construction monitoring since the instrumentation interferes with construction activities and will likely become damaged. A balance of cost, precision, frequency of measurement, and level of interference with activities needs to be accounted for in designing a field instrumentation program for construction monitoring. Table 1 summarizes potential types of instrumentation which may be of use for field monitoring of deformations of transportation structures using the above mentioned criteria. Instrumentation for each site will be selected on a case by case basis to achieve the best combination of information and cost effectiveness. As presented in the budget summary, approximately $2000 in instrumentation and monitoring will be used for each foundation type at a given site ($30,000 total, over 5 shallow foundation sites, 5 deep foundation axial loading, and 5 deep foundation lateral loading). For cases of deep foundation projects where axial and lateral foundation movements will be monitored, the combined monitoring budget increases to $4000.

Transmission of these data using radio frequency transmitters, modems or cellular modems, or Ethernet connections allows for relatively easy access to digital measurements from remote locations. Measurement techniques identified with ‘high’ measurement frequency in Table 1 are considered compatible with remote data transmission, other methods are not. Temperature measurements at strain gauge locations are necessary for accurate measurements over time and are planned for use in the program, when appropriate.

Table 1. Relative characterization of some types of instrumentation for load and deformations measurement of transportation structures

Sensor / technique	Application	Cost	Precision	Measurement Frequency	Interference
Traditional optical surveying	Surface movement	Med / Low	Med / High	Low	Low
Automated optical surveying system	Surface movement	High	Med / High	High	Low
Deep benchmarks with optical surveying	Movement at depth	Very High	Med / High	Low	Med
LVDT displacement transducers	Surface movement	High	High	High	Very High
Photogrametry / Particle Image Velocimetry (PIV)	Surface movement	Low	Med / High	Med / High	Low / Med
Local Differential GPS Network	Surface movement	High	Med / High	High	Low
Inclinometers	Rotation / p-y curves	Low	Med / Low	Low	High
Clinometers / Tiltmeters / Accelerometers	Rotation / p-y curves	High / Med	Med / Low	High	Low
Assessment of Construction Schedule	Load at top of Foundation	Low	Low / Med	High	Low
Electrical resistance strain gauged "load cell"	Load at top of Foundation	High	High	High	Low
Electrical resistance strain gauges for axial load	Vertical def. / t-z & q-z curves	High	High	High	Low
Electrical resistance strain gauges for bending	Horizontal def. / p-y curves	High	High	High	Low
Piezometers	Consolidation Settlement	High	High	High	Low

6.1.2. Database study

The development of 'design methods' are often based on calibration of theoretical, semi-theoretical, or empirical models using case histories. These databases are often relatively small in size, based on data of variable quality, and only partially representative of foundation geometries, soil conditions, or foundation loading conditions for transportation structures in Wisconsin. For instance, a recently published database of case histories of laterally loaded piles (Anderson et al. 2003) had only 7 lateral load tests, which included a wide range of soil types and pile installation methods. Since that time only two case histories have been added to that database of lateral pile load tests with adjacent pressuremeter test data (Cosentino et al. 2006). While Briaud (1986) discuss a database of 27 lateral pile tests with adjacent pressuremeter test data, the neglect of these previous tests highlights that current design methods are predominantly based on *local correlations* which have not been calibrated in Wisconsin. The amount of lateral load test data with adjacent DMT soundings is even more limited than that for the PMT, with only one test discussed by Robertson et al. (1989) and three tests discussed by Gabr et al. (1994). In a review of a database of axial load tests on driven piles in siliceous sands with adjacent CPT data, Schneider et al. (2008b) observed that due to the large number of variables known to influence pile behavior, analysis of their full 77 pile database of load tests was necessary to assess reliability of design methods. Smaller 12 to 32 pile database 'subsets' did not cover an adequate range of soil densities and pile geometries for reliable extrapolation to design situations that differed from typical database characteristics.

This study will create new databases of axial and lateral load tests on deep foundations, as well as load tests on shallow foundations. Data will primarily come from the geotechnical literature, such as the sources previously discussed. The 6 static axial load tests and 3 lateral load tests from the Marquette Interchange project, along with the 24 PMT, 2 DMT and 27 CPTUs from the geotechnical investigation, will provide a good stating point for expanding existing databases to include soil conditions typical of Wisconsin. Local DOTs, such as the Minnesota DOT, will be approached to get additional test information in similar geologic conditions. The database studies will be supplemented with parametric studies using finite element (FE) methods (using the software package PLAXIS with linear elastic-plastic and nonlinear-hardening soil models) to assess the influence of extrapolation from soil conditions and pile geometries typical of the databases to soil, pile, and loading conditions more typical of foundations for transportation structures in Wisconsin.

6.2. Field testing programs

Field testing programs at WisDOT project sites will be organized through discussions with the Project Oversight Team (POT). The sites will be selected to cover a range of different types of transportation projects as well as different geologic conditions typical of Wisconsin. The results of the database study and FE analyses in Phase I of the research project will be used to highlight areas of uncertainty that will subsequently be discussed with the POT to aid in selection of appropriate sites.

Investigations of structural movements will be performed in association with 5 WisDOT shallow foundation projects and 5 WisDOT deep foundation projects. Project types and soil conditions will be decided through discussion with the POT at the beginning of the project, and updated after the detailed literature review. Glaciated clays and silty clays, along with sands and gravels are anticipated to be the major soils types encountered during the project. Movements of deep and shallow foundations for full retaining and integral abutments will be included in the program. Figure 5 presents conceptual instrumentation layouts for possible deep and shallow foundation projects. At a minimum, structural movements will be monitored using optical surveying and loads will be assessed using the construction schedule. To monitor cyclic loading of integral abutments over time, temperature and tilt / inclination sensors are planned to be used.

Lateral pile investigations will be performed in association with 5 WisDOT projects, as decided on through discussions with the POT. Depending upon the project, continuous monitoring of lateral loads at the pile head and the distribution of lateral loads along the length of the pile can be used to assess site specific p-y curves over the mobilized displacement. This has been illustrated in Figure 5a for structural movement monitoring.

For shallow foundation sites an anticipated monitoring plan will consist of a combination of traditional surveying methods complimented by micro-electromechanical (MEM) accelerometers embedded in the foundation. A strain gauged load cell will be cast at the connection to the footing so that load and settlement can both be monitored.

For deep foundation sites a similar methodology will be used for axial and lateral loading. Head load will be measured by strain gauging the top of the pile. Deflections will be measured by a combination of traditional surveying methods and MEM accelerometers. Strain gauges will also be attached at three points along the vertical length of the pile to provide additional information on axial load transfer and distribution of bending moment due to lateral loading of the piles.

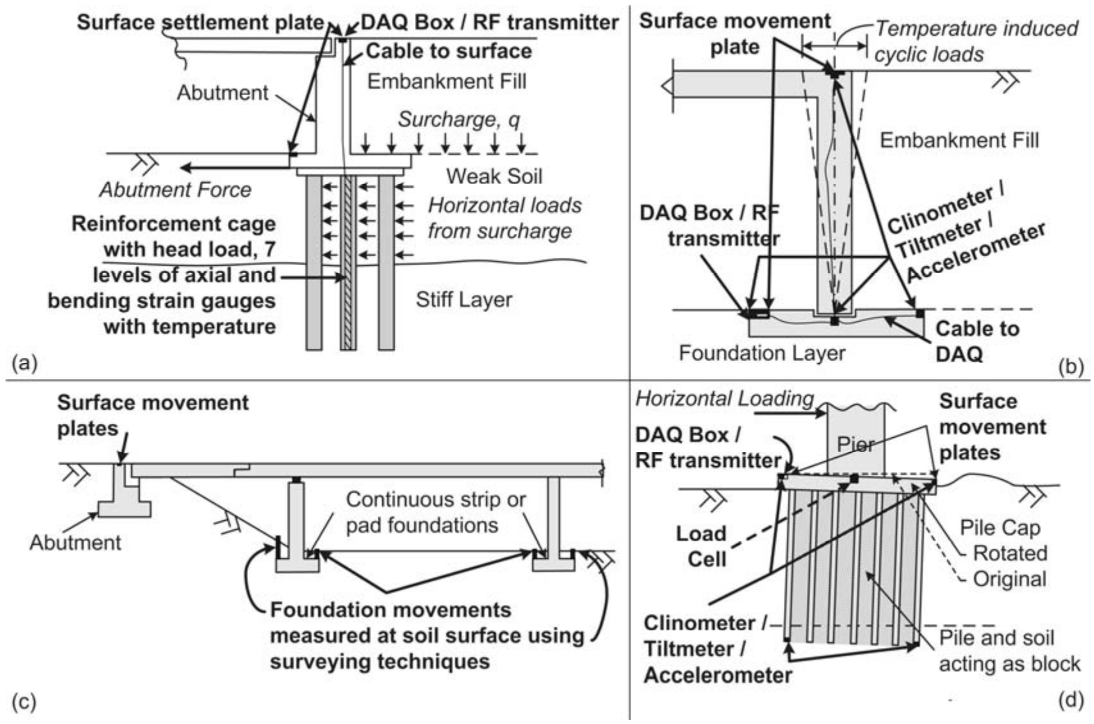


Figure 5. Conceptual instrumentation layouts (a) retaining wall supported on piles; (b) integral abutment on a shallow foundation; (c) near surface shallow foundation; (d) pile group

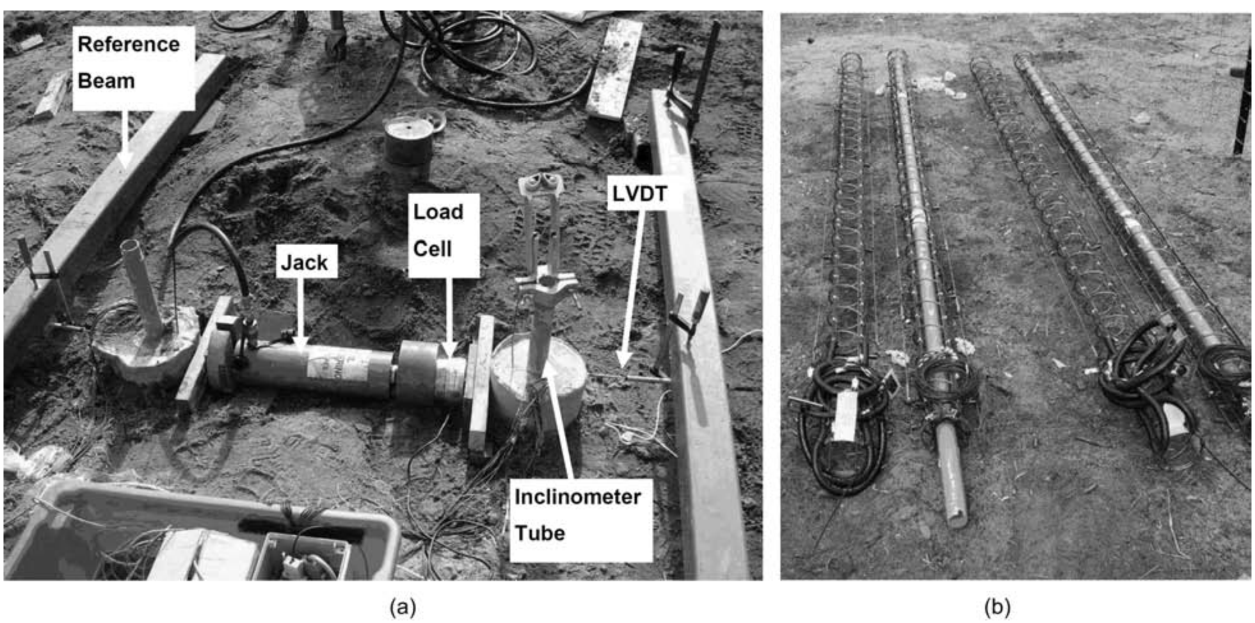
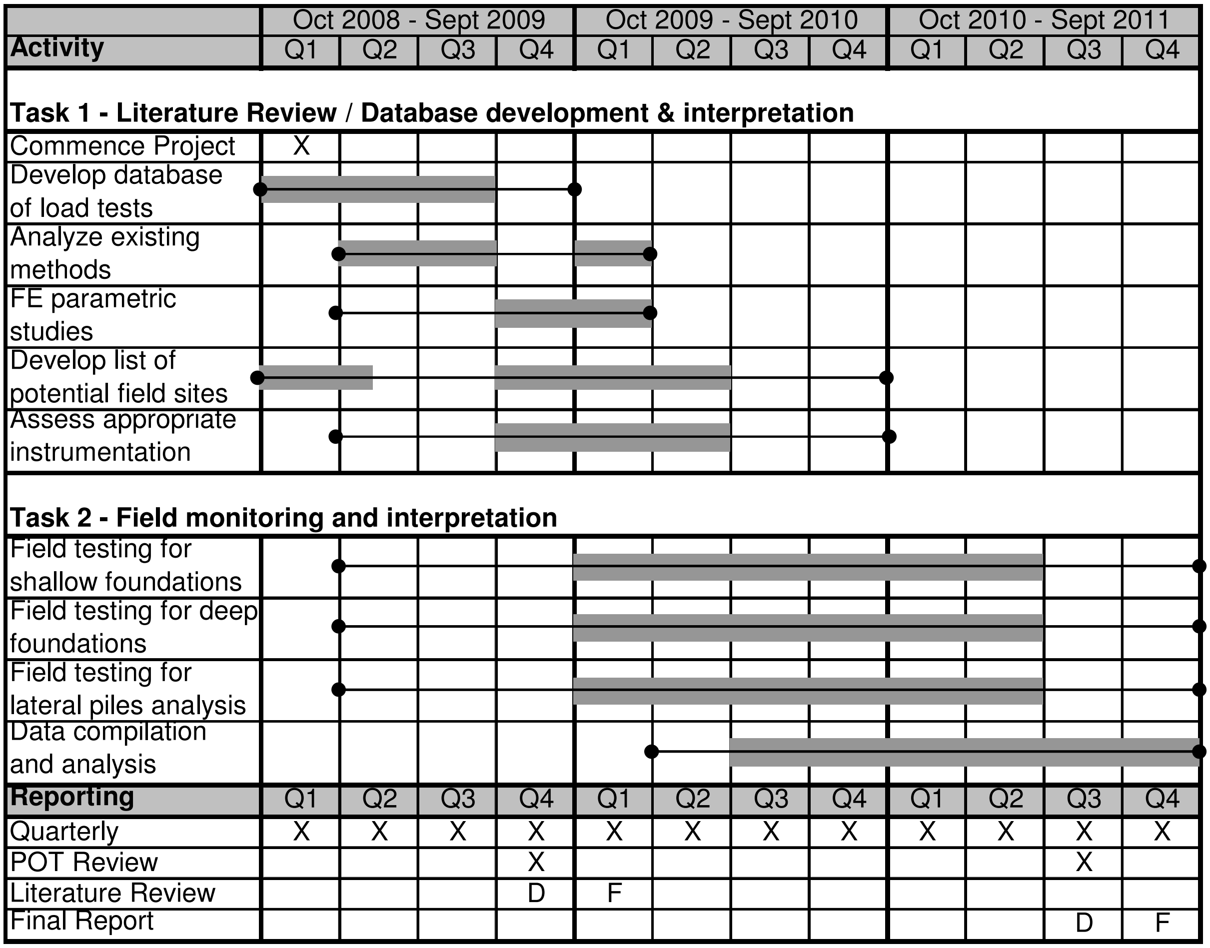


Figure 6. Photographs of (a) paired lateral pile testing; and (b) strain gauged cage with inclinometer casing (after Luff 2007)

7. WORK TIME SCHEDULE

The project is anticipated to start on 1 October 2008 and continue for up to 3 years. A three month period of review by the Project Oversight Team (POT) is accounted for in the scheduling. Figure 7 presents the planned work time schedule for the project. A summary of hours for each phase is included in Section 9, Budget Requirements.



D = Draft Report; F = Final Report

Figure 7. Planned work-time schedule

8. REPORTS

Quarterly reports will be prepared to summarize the progress of the project. After completion of the detailed literature review, a report will be presented to the Project Oversight Team (POT). This report will summarize the literature review and present preliminary findings as well as a work plan for the remainder of the study. The work plan will be updated after discussions with the POT. A final report summarizing the detailed literature review and field measurements will be prepared. The report will discuss advantages and limitations of the data and analysis methods, as well as provide tables of standardized foundation deformations for typical soil conditions, foundation types, foundation geometries, and foundation loads. Forty (40) copies of the final report will be provided. Electrical version of the reports will also be provided.

Qualifications of the Research Team

Assistant Professor James A. Schneider, PE

Dr. Schneider has been involved in geotechnical research and practice over the past 12 years, with a primary focus on **site characterization using in situ tests** and **foundation design**. After completing his masters thesis at Georgia Tech (Atlanta, GA), he was a full time consultant with Geosyntec (Atlanta, GA) and Fugro (California), earning his professional registration **(PE) in California**. Experience gained during consulting has included (i) axial pile analyses; (ii) lateral pile analyses; (iii) bearing capacity and settlements of shallow foundations; (iv) site characterization, as well as other issues related to bridge improvements, port and harbor structures, offshore structures, embankments, and navigation channel deepening. He completed his PhD thesis at The University of Western Australia on the analysis of piezocone data for **displacement pile design**. During the time of his thesis research, he was **actively involved with the modification of** the American Petroleum Institute recommended practice for fixed offshore structures (**API RP2A**), and was **co-developer of** one of the **CPT based axial pile design methods included in the design guidelines**. The API study included collection and review of a database of load tests on open and closed ended piles in sand with adjacent in situ test data.

Through research and practice Dr. Schneider has gained significant experience with **field testing** and **instrumentation**, including the operation of cone penetration testing (CPT) rigs at Georgia Tech and The University of Western Australia. During this research he has performed (i) cone (**CPT**), piezocone (**CPTU**), and seismic piezocone tests (**SCPTU**); (ii) flat plate dilatometer tests (**DMT**); (iii) self boring pressuremeter (**SBP**) tests; (iv) vane shear tests (**VST**), and interpreted data from these and other tests types in a variety of soil conditions. While at Fugro, he was involved in installation and monitoring of **field instrumentation** for the **Port of Los Angeles Pier 400 Extension** as well as Channel Islands Harbor revetment stabilization, using (i) piezometers with remote logging; (ii) inclinometers; as well as (iii) sondex tubes and surface monuments for settlement monitoring. He has **instrumented and performed over 50 field load tests** for axial and lateral loading of pile foundations, as well as axial loading of shallow foundations. His foundation research has included analysis of the effects of time between construction and loading as well as creep on load-settlement response.

Dr. Schneider has previously supervised students on topics including, axial pile design, soil liquefaction, soil characterization, and slope stability. He is a reviewer for the ASCE Journal of Geotechnical and Geoenvironmental Engineering, Canadian Geotechnical Journal, ASTM Geotechnical Testing Journal, Journal of Geotechnical and Geological Engineering, as well as conference proceedings. During the duration of this project, teaching should take up 25% of his time, with professional activities requiring another 5%. **This leaves 70% of the PIs time for other endeavors, such as this project.**

Selected relevant publications:

Schneider, J.A., Xu. X., and Lehane, B.M. (2008). "Database assessment of CPT based design methods for axial capacity of driven piles in siliceous sands." *ASCE Journal of Geotechnical and Geoenvironmental Engineering*, (in press).

Schneider, J.A. (2008). "Separating influences of yield stress ratio (YSR) and partial drainage on piezocone response." *Australian Geomechanics*, (in press) (Winner of **Baden Clegg Award**).

Lehane, B.M., Doherty, J.P., and Schneider, J.A. (2008). "Settlement prediction for footings on sand." **Keynote Paper**, *Proc. Pre-Failure Deformation Characteristics of Geomaterials*, Atlanta, (in press).

Fahey, M., Schneider, J.A., and Lehane, B.M. (2007). "Self-boring pressuremeter testing in Spearwood dune sands." *Australian Geomechanics*, 42(4), 57-71.

Schneider, J.A. (2006). "Impact of offshore site investigation practice on reliability of axial pile design in siliceous sands." *31st Annual Conference on Deep Foundations*, Deep Foundation Institute: 623-638. (Selected as **Best Student Paper**)

Mayne, P.W., Schneider, J.A., and Martin, G.K. (1999). "Small- and large-strain soil properties from seismic flat dilatometer tests." *Proceedings, Pre-failure deformation characteristics of geomaterials*, 419-426.

Prof. Tuncer B. Edil, PE, Senior Project Advisor

Prof. Tuncer B. Edil, PE has been an active researcher and educator for nearly 35 years at the University of Wisconsin. He has undertaken several projects relating to highway construction. He also conducted fundamental studies relating to soil strength and compression behavior including the effects of compositional and geological factors. Prof. Edil introduced the wide spread use of CU triaxial compression testing in Wisconsin 30 years ago and has conducted triaxial compression and consolidation tests for the WisDOT before helping WisDOT acquire its own testing capability. He also conducted research on shaft resistance of piles installed by different methods and surface roughness. He served on WisDOT's Subgrade Task Force, which produced a series of recommendations including the use of select materials for stabilization of poor subgrades during construction. Prof. Edil also serves on the Technical Oversight Committee for geotechnical research at WisDOT. He has completed research projects for WisDOT on working platforms for construction platforms, including geosynthetic-reinforced granular platforms and other topics. He is a member of TRB and serves on several technical committees. He currently is serving as Research Director of the Recycled Materials Resource Center established by the FHWA. Dr. Edil is recipient of numerous personal and team/project awards from ASCE, ASTM, IFAI, and other organizations. He is given the 2007 Special Science Award by the Scientific and Technological Research Council of Turkey.

10. FACILITIES AVAILABLE

The Department of Civil and Environmental Engineering and the Geological Engineering Program have numerous devices available for field instrumentation and monitoring as well as site characterization activities. Additionally, new in situ testing equipment is currently being developed/acquired and should be available by fall 2008.

10.1. Field & Laboratory Equipment

Surveying equipment at the University of Wisconsin – Madison includes total stations as well as a GPS surveying facility. GPS surveying equipment and software includes:

- 3 Trimble 4000SSi dual frequency GPS receivers
- 3 Trimble dual frequency choke ring antennas
- 3 Trimble 4600LS single frequency GPS receivers (each with integrated L1 antenna)
- 4 antenna bipods
- 2 antenna tripods
- Trimble GPSurvey version 2.35*
    - cm level differential static positioning
    - cm level differential kinematic positioning (no RTK hardware, post process only)
- JPL GIPSY and Auto-GIPSY
    - mm level absolute static positioning

Geotechnical field testing equipment at the University of Wisconsin – Madison includes:

- Drilling Rig
- Piezocone penetrometer
- Dilatometer
- Borehole pressuremeter with radial strain measurements (in fabrication)
- Ground Penetrating Radar
- Seismographs
- Electrical Resistivity
- Magnetometers

Additionally the Geo-Engineering Laboratories are fully equipped to perform both standard and specialized geotechnical, and geoenvironmental tests as applied to processes in the near subsurface. A large number of triaxial cells are available for the triaxial compression, consolidation, resilient modulus, and permeability characterization of soils. Six newly installed computer controlled load frames are available for different types of compression testing. The Geo-Engineering laboratory also includes a broad variety of general supplies needed for preparation of the specimens. Triaxial cells have been equipped with transducers for **measurement of local strains**, which is paramount for the evaluation of nonlinear stiffness characteristics of soils.

The Geo-Engineering Laboratories are fully equipped with specialized instruments and transducers for the evaluation of the saturated and unsaturated geomaterial response under low-amplitude elastic and electromagnetic waves. This collection of instrumentation includes: Stokoe-type resonant column, P and S-wave ultrasonic sensors, 10 Hz-10 kHz PCB miniature piezocrystal accelerometers, bender-elements, TDR systems, HP 4192A low-frequency impedance analyzer, and HP 8752A high-frequency network analyzer. These sets of instruments are complemented with peripheral electronics, including data acquisition systems, digital storage oscilloscopes, charge amplifiers, power amplifiers, filter/amplifier, electronic multimeters, and signal generators.

The laboratory is managed by a full-time academic staff member with a BS in Civil Engineering and an MS in Geotechnical Engineering who will assist on the graduate student in proper usage of the laboratory equipment and testing preparation.

10.2. Computing Facilities

Computer-Aided Engineering Center (CAE) is a College of Engineering facility available to all students. CAE provides engineering students with state-of-the-art computing resources, including word processing, spreadsheets, graphs and plots, mathematical and statistical analysis, to aid in research, reports, and presentations. Color and laser printers, scanners, zip drives, digital cameras, and removable media also are available.

Data analysis will be conducted using PCs. Each student in the University of Wisconsin's Geo Engineering Program is supplied with a PC for use in their office. The offices also include a variety of scanners, laser printers, and other computing equipment that will be used for data analysis and preparation of publications.

Software available for foundation design include:

- LPILE (load transfer analysis of laterally loaded piles)
- Plaxis (V. 8) (geotechnical finite element analyses)
- ANSYS (finite element analyses with geomechanical soil models)
- RATZ (load transfer analysis of axially loaded piles)
- PYGMY (load transfer analysis of laterally loaded piles)

As well as macros written for development and analysis of pile load test databases.

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